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Review article

Preventing and mitigating health risks of climate change

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ABSTRACT

Global environmental changes, driven by the consequences of human activities and population growth, are altering our planet in ways that pose current threats to human health, with the magnitude of these threats projected to increase over coming decades if additional, proactive actions are not taken. Global changes, unprecedented in their geospatial and temporal scales, include climate change, marine pollution, ozone layer depletion, soil degradation, and urbanization. Climate change is the best studied. The health risks of a changing climate will become increasingly urgent as climate change affects the quantity and quality of food and water, increases air pollution, alters the distribution of vectors/pathogens and disease transmission dynamics, and reduces eco-physical buffering against extreme weather and climate events. Health systems urgently need to be improved to effectively address these emerging challenges. This paper provides an overview of the health consequences of climate change, and discusses how health risks can be minimized and avoided via mitigation and adaptation pathways.

1. Introduction

Humans are changing planet Earth through burning of fossil fuels, urbanization, deforestation, agriculture, and industrial processes. Since the Industrial Revolution, atmospheric concentrations of greenhouse gases (GHGs) have increased significantly, particularly over the past five decades. The current atmospheric concentration of carbon dioxide (CO_2), the major GHG, is 411 ppm, higher than any time in the past 800,000 years (Intergovernmental Panel on Climate Change (IPCC), 2018; NASA 2019). The global mean surface temperature is now about 1.0 °C above pre-industrial levels, with consequences for human and natural systems that are detrimental for health and livelihoods. With continued greenhouse gas emissions at the same rate as over the past decade, global warming is projected to reach 1.5 °C between 2030 and 2052 (Intergovernmental Panel on Climate Change (IPCC), 2018). Further, the rate of climate change accelerated in about the 1970s. For example, average global temperature for 2006–2015 was 0.87 °C above a pre-industrial baseline (World Meteorological Organization (WMO), 2018). For comparison, the average increase above the same baseline for the most recent decade 2009–2018 was 0.93 ± 0.07 °C, and the average for the past five years, 2014–2018 was 1.04 ± 0.09 °C. In the fifth assessment report (AR5), the Intergovernmental Panel on Climate Change (IPCC) concluded that human-produced greenhouse gases such as carbon dioxide, methane, and nitrous oxide caused most of the observed increase in Earth's temperatures over the past 50 years (Intergovernmental Panel on Climate Change (IPCC), 2014). Each additional unit of warming is projected to increase climate-related risks for nearly all natural and human systems. These risks largely depend on the pattern and pace of climate change, geographic location, levels of socioeconomic development, resilience and vulnerability, and on implementation of adaptation and mitigation options (Intergovernmental Panel on Climate Change (IPCC), 2018; NASA 2019).

Within a global context, '1.5 °C warming' may result in vastly different temperatures at different regions due to variations in the magnitude and rate of warming in particular locations; these will interact with society's exposure and vulnerability to affect climate-related risks (Seneviratne et al., 2018). At 1.5 °C of warming, temperatures will be much higher than the global average in some regions, with some regional extremes potentially reaching dangerous levels for ecosystems and societies. This research supports pursuing policies consistent with the goal of the Paris Agreement to keep warming well below 2 °C.

Climate change-related risks are increasingly affecting population health and health systems. There are complex inter-relations among climate, social, and environmental conditions, and human health. For

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example, climate change affects the quantity and quality of food and water; increases air pollution, alters the distribution of vectors/pathogens and disease transmission dynamics; and reduces eco-physical buffering against extreme weather and climate events (Ebi et al., 2018; McMichael, 2013; Tong et al., 2016; Watts et al., 2018). In the coming decades, climate change is expected to alter the patterns of many ambient exposures and disasters, including extreme temperatures, heat waves, wildfires, droughts, and floods, with potentially severe consequences for many communities (Anderson et al., 2019). These exposures in turn can affect risks for a variety of human climate-sensitive health outcomes. To protect human health, it has become urgent to effectively address these risks, in the context of rapid changes in climate and in development choices that affect health (Intergovernmental Panel on Climate Change (IPCC), 2018; Cheng et al., 2019).

We review climate change-related health risks within a global context, and discuss how these risks could be minimized and avoided via adaptation to and mitigation of climate change. Additionally, we highlight that how quickly change occurs is perhaps as important as reducing the magnitude of change. There is large variability in health risks over spatial and temporal scales. With particular reference to Australia and USA, we explore major adaptive strategies to prepare for and manage the impacts of climate change.

2. Health risks: increased recognition by policymakers

Policymakers are increasingly recognizing that climate change poses major risks to human health and wellbeing (Smith et al., 2014; Patz et al., 2014; Watts et al., 2018; Haines and Ebi, 2019). Policy and scientific assessments over the past two decades included consideration of the risks of climate change for energy, water and food security, agriculture, industry, economic activity, physical infrastructure, and biodiversity. These assessments advanced understanding of the wide spectrum of threats posed by climate change to human and natural systems. Increased appreciation of risks to human health and wellbeing helped align scientific investigation with public concern and policy discussion. From the perspective of sustainable development, health consequences associated with extreme weather events (e.g., heatwaves, bushfires, droughts, and floods), vector-borne pathogens, and undernutrition are projected to result in the highest burdens of disease from climate change (Fig. 1).

In the interface of climate and health, there has been increasing recognition that the rate of climate change can be as important as the magnitude of change over the short term; in some cases, it may be more important. For example, the accelerating consequences of more frequent and intense extreme weather and climate events are increasing public awareness of the challenges of a changing climate, including 2017 flooding from hurricanes in the U.S., 2018 California bushfires, 2018 European floods, and 2019 Queensland heatwaves. Further, the burden of adverse climate-sensitive health outcomes is affected by the variability in the rate and magnitude of climate change across regions (Intergovernmental Panel on Climate Change (IPCC), 2014; World Meteorological Organization (WMO), 2018). These issues pose significant challenges to local governments for developing and deploying effective mitigation and adaptation policies.

Health authorities are not only responsible for promoting physical and mental health; preventing disease, injury, and disability; and improving health care systems; but are also responsible for developing and implementing adaptive strategies to reduce climate change-related health risks. Public health adaptive interventions can be categorised into three tiers: primary, secondary and tertiary prevention (Butler and Harley, 2010). The purpose of primary prevention is to decrease exposures to climate change-related risk factors; secondary prevention aims to reduce the onset or slow the progression of climate change-related health effects; and tertiary prevention aims to treat and manage health impacts that have already occurred.

For example, the frequency, intensity, duration, and geographic extent of heatwaves are projected to increase with additional climate change (Intergovernmental Panel on Climate Change (IPCC), 2014). As a result, associated health risks are projected to substantially increase, if not further actions are undertaken (Guo et al., 2018). Primary prevention could reduce the 'exposure' of people to thermal stress. Mitigation of greenhouse gas emissions is a critical component of primary prevention. Primary prevention includes providing advice to communities and individuals on effective approaches for reducing or avoiding exposure to heat, to maintain core body temperature. Secondary prevention would identify those who are particularly vulnerable to heat exposure, such as older adults, children, pregnant women, and persons with underlying cardiorespiratory illnesses, and would provide them with information on effective actions for increasing their resilience during heatwaves. Tertiary prevention would provide post-event support, treatment, and management to reduce health consequences (e.g., morbidity and mortality) during and after a heatwave.

Due to a wide range of climate-related risks and prevention interventions, health-protecting activities should be undertaken not only by health systems but also by other relevant sectors of government and industry, as well as by individuals and communities. An interdisciplinary, holistic approach is required to design and implement these activities.

3. Causal pathways to health risks

Extreme weather events can pose direct risks to human health and to society; these events are associated with preventable deaths and hospitalizations. These events may also cause stress and mental illnesses that can result in a substantial burden to the community (Haines and Ebi, 2019). Additionally, climate change can also affect individual health behaviors. For instance, evidence suggests nonlinear impacts of rising temperatures on health-promoting bicycle ridership, with increases in bicycling by mid-century in New York City. This trend may reverse as temperatures continue to rise further (Heaney et al., 2019).

Indirect risks include changes in the transmission pattern of climate-sensitive infectious diseases, interactive effects between air pollution and weather conditions, and declines in the quality and quantity of food and freshwater. Climate change may alter the distribution of vectors and pathogens and also affect people's behavior. All these factors can contribute to the changes in patterns of infectious diseases. Further, changes in weather conditions (e.g., temperature, rainfall, and humidity) can influence atmospheric concentrations of toxic air pollutants (e.g., particulates, ozone, and nitrogen dioxide) and of aeroallergens (e.g., pollens and spores) that affect population health. Climate change can also cause large scale and irreversible damage to ecosystems, such as coral reefs and coastal mangroves. For example, it is projected that coral reefs are projected to decline by a further 70–90% at 1.5 °C warming (*high confidence*) with larger losses (> 99%) at 2 °C warming (*very high confidence*). Such a loss would decrease food security and livelihoods in affected coastal communities. The risk of irreversible loss of many marine and coastal ecosystems increases with additional warming, especially at 2 °C or more (*high confidence*) (Intergovernmental Panel on Climate Change (IPCC), 2018).

Large contributions to the future disease burden of climate change could arise from diffuse and delayed impacts of social, economic, and demographic disturbances, although they are more difficult to quantify. For example, increases in the migration of vulnerable populations (e.g., low-lying island countries) and the loss of livelihoods and life stocks (e.g., Sub-Saharan Africa) could result in the broad range of adverse health consequences – mental, physical, nutritional, and emotional.

4. Vulnerability and inequity

People who have low-income, are poorly-resourced, or live in geographically isolated circumstances are typically more vulnerable to climate-related risks. In general, populations in low- and middle-

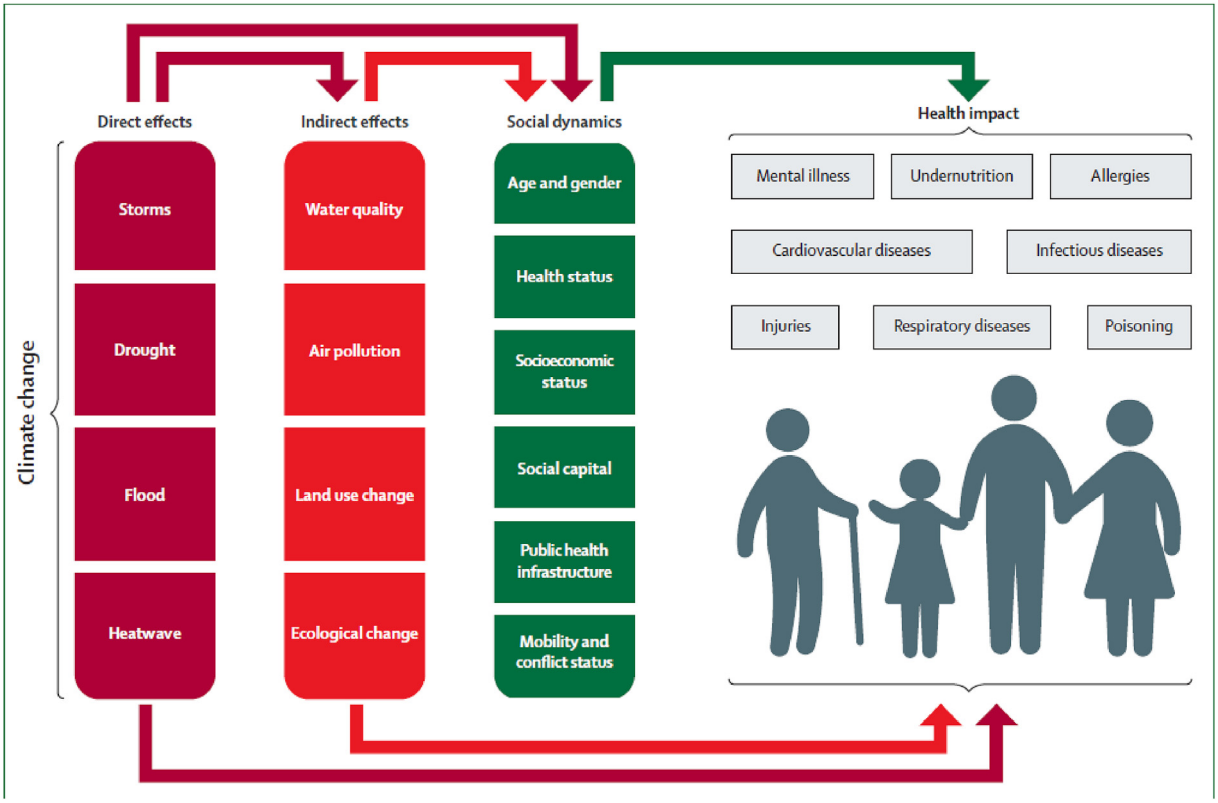

Fig. 1. The health risks posed by climate change (Adapted from Watts et al., 2015).

income countries are at higher risk than those in high-income countries because the former has limited financial and health system resources. Additionally, there is differential vulnerability within populations in higher (or lower) income countries. For example, in the USA, the risks of serious illnesses and deaths associated with the 1995 Chicago heatwave, Hurricane Katrina in New Orleans in 2005, and California forest/bush fires in 2017–18 differed greatly between socio-economic and ethnic subpopulations (Ali et al., 2017; Morrison et al., 2018; Semenza et al., 1996). Inequity across subpopulations could lead to differential vulnerability in the community.

The vulnerability of a particular population or sub-population is determined by the following factors (National Research Council (NRC), 2013; World Health Organization (WHO), 2013; Watts et al., 2018):

(i) the nature and magnitude of the hazards posed by climate change;
(ii) the extent of exposure to these hazards;
(iii) the sensitivity and resilience of the exposed populations; and
(iv) the community capacity to respond and manage the health risks.

Panel 1 shows some major vulnerable sub-populations in Australia and USA. Clearly, the vulnerability of a particular sub-population is determined by their characteristics (e.g., material resources, socio-demographic factors, and public health infrastructure).

- Indigenous communities facing extreme heat, drought, and food/water shortages;
- Dwellers in regions where climate-sensitive infectious diseases (e.g., dengue and Lyme disease) may tend to spread;
- Rural communities exposed to long-term droughts (e.g., New South Wales and Queensland in Australia);
- Older and frailer persons, people with chronic diseases, and those with poor housing conditions (e.g., no air conditioner) who are most vulnerable to heatwaves;
- Young children and pregnant women with insufficient thermoregulation functioning;
- Low-lying coastal communities at risk of rising sea levels; and
- Residents living in current and potential cyclone/hurricane risk regions.

Panel 1. Vulnerable sub-populations in Australia and USA

It is important to identify and focus on highly vulnerable communities and sub-populations because addressing the issue of health inequality will enhance policies and programs to reduce and prevent climate-related risks. Consideration of differential vulnerability has significant implications for designing and implementing intervention options.

How to prioritise responses to climate change risks to health? Both targeting those most affected and making conditions safer for everyone are critical. Sometimes an effective public health intervention focuses on highly vulnerable sub-populations (e.g., moving people with chronic diseases to a cooling centre during a heatwave), but other times, population-wide interventions may have better benefit:cost ratios (e.g., better building codes, city planning regulations for green space, and heat warning systems). Health for all is a fundamental goal and a key principle for mitigation and adaptation to manage climate change-related health risks.

5. Increasing the level of ambition for adaptation and mitigation

Policies to mitigate greenhouse gases and to increase the resilience of health systems to climate-related hazards should be developed in parallel, because even if GHG emissions could be completely eliminated today, additional climate change (less than 0.5 °C) is unavoidable over the next few decades due to the inherent inertia in the complex climatic system, which will increase the magnitude and pattern of health risks over the next few decades (Intergovernmental Panel on Climate Change (IPCC), 2018). Health adaptation research and practice is progressing,

but the levels of investment and ambition are inadequate to the needs. Increasing resilience will likely be best achieved through collaboration across sectors, because many of the health risks of climate change are influenced by decisions taken in other sectors. For example, urban sprawl into forests is likely to increase the risk for mosquito-borne diseases (Mackenzie et al., 2017). Irrespective of political boundaries and resource constraints, health authorities need better understanding and additional investments to cope with the increasing burden of climate-sensitive health outcomes as climate change proceeds.

A well thought-through and coordinated adaptation plan needs to be developed at different government levels, with the effectiveness of each strategy affected by multiple factors. For example, Panel 2 indicates key adaptive measures to reduce heatwave-related mortality/morbidity that can be considered and adopted by health authorities from local to the international level.

- Development of heat/health early warning systems (HHEWS);
- Urban planning that explicitly considers the 'heat island' and 'greenness' effects;
- Housing standards that account for increasing average and extreme temperatures (e.g., insulation and installment of air conditioner);
- Community education programs about the health risks of heatwaves and protective measure to alleviate these risks; and
- Creation and refinement of climate-resilient health-care facilities including ambulances, clinics, hospitals (emergency departments), and community health centers.

Panel 2. Key adaptive measures to reduce heatwave-related health risks

Additional research in the following areas could provide useful insights for developing local to national measures to increase resilience to climate change (Ebi et al., 2018):

(1) Assess and prioritize the health risks of climate change over spatial and temporal scales. Climate change will likely affect communicable and non-communicable diseases, with changes in the magnitude and pattern of climate-sensitive health outcomes; as thresholds are crossed, some of these changes could be rapid and large. Proactive prioritization using environmental information (e.g., projected changes in temperature and precipitation as well as air pollution) could prevent additional morbidity and mortality.
(2) Understand the best way to use surveillance data to identify disease thresholds, interface with emergency preparedness, and project future burdens. Research is needed to monitor the robustness of health surveillance systems as climate change-related health threats emerge and intensify in some regions. It is also critical to identify key environmental variables, including proxy data (e.g., pollen, harmful algal blooms, and dominant vector species) to include in surveillance systems, and to link environmental and health outcome data. Further, long-term studies are needed to help quantify the relationships between meteorological variables and health outcomes, to estimate the extent to which climate change has already altered disease burdens and/or facilitated changes in the distribution of vectors and pathogens across time. This is essential to inform evidence-based health policies.
(3) Project future climate change-related health risks under different climate and socioeconomic scenarios to design and implement effective and efficient interventions.
(4) Incorporate data mining and machine learning into iterative management cycles, developing appropriate models for decision making and building capacity for further adaptation.
(5) Effectively communicate the health risks of climate change to the public and to policymakers, providing information regarding preparedness and protections against climate-sensitive hazards.
(6) Motivate and inform policy decisions, prioritize ongoing investments in health protection related to climate change, and characterize returns on health protection investments at different time horizons in a changing climate.

Many of these themes relate to the priority of increasing resilience to other threats to health systems, such as preparation for pandemic disease. The proposed research priorities can mainstream adaptation and resilience into a wide range of hazards.

However, climate change is seldom framed as a health issue, and hardly ever are national departments of health the leading agencies for mitigation and adaptation. Why is this? Reasons include that most governments put economy in front of health and are concerned more about economic impacts of climate change. Also, it is extremely difficult to attract sufficient attention from health departments because they focus more on urgent health issues (e.g., patient care). Climate change was not regarded as a health emergency until recently (Solomon and LaRocque, 2019). Communications between climate scientists, epidemiologists, and health policy-makers need to be improved at all levels, from local to global. Additionally, public health actions are also urgently required to cope with the increasing impacts of climate change. Both top-down and bottom-up approaches are needed to bring health and climate co-benefits (Nilsson et al., 2012).

6. Conclusions

Given the urgency of anthropogenic global climate change and strategies to deal with its consequences, an essential component of policies and measures is to strengthen cross-sectoral collaboration, to work more intensively and effectively to curb greenhouse gas emissions, and to increase the level of ambition and investment in policies, technologies, and tools to minimize threats to population health and well-being and to adapt to unavoidable threats over the next few decades. These efforts can facilitate thinking about how best to generate useful and useable knowledge to reduce health risks, including how to include the protection of population health in policy analyses and development choices at all levels of government, from local to regional, national and global.

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